



Energy, Mines and
Resources Canada

Énergie, Mines et
Ressources Canada

CANMET

Canada Centre
for Mineral
and Energy
Technology

Centre canadien
de la technologie
des minéraux
et de l'énergie

MECHANICAL PROPERTIES OF ROCK SAMPLES FROM ATIKOKAN, ONTARIO

A. Annor and R. Jackson
Rock Mechanics Laboratory

October 1984

This document is an abstract
of a report prepared by the
author for the purpose of
providing information to the
public and to the
Ministry of Energy, Mines and
Technical Services.
The opinion of the author is
not necessarily shared by
the Mineral and Energy Technology
(CANMET)

Ce document est un résumé
d'un rapport préparé et rédigé
par l'auteur pour le compte de
la Commission canadienne de
l'énergie, des mines et des
services techniques.
L'opinion de l'auteur n'est
pas nécessairement celle de
la Commission canadienne de
l'énergie, des mines et de
l'énergie (CANMET)

35 pp

ENERGY RESEARCH PROGRAM
MINING RESEARCH LABORATORIES
DIVISION REPORT ERP/MRL 84-63(TR)

MICROMEDIA

MAY 13 1985

MECHANICAL PROPERTIES OF ROCK SAMPLES FROM ATIKOKAN, ONTARIO

by

A. Annor and R. Jackson

ABSTRACT

Mechanical property measurements were carried out on rock samples from the Eye Dashwa Lake's pluton, as part of a Atomic Energy of Canada Limited directed comprehensive geomechanics research program, to find a safe means of disposing of nuclear waste in deep underground rock bodies.

Fifty four test samples of mainly granitic composition originated from the Eye Dashwa Lake's pluton, near Atikokan, Ontario. The samples were tested for uniaxial compressive strength, Young's Modulus, Poisson's ratio and compressive wave velocity values.

The test results indicated uniform variation of deformational properties (E and ν) with depth. Uniaxial compressive strength and zero pressure compressive wave velocity values remained relatively uniform with depth. There were, however strength reversals in these properties at certain elevations due to the effects of stress relief on the laboratory samples after drilling.

The test results compare favourably with data in the published literature on granitic rock of similar composition. There were also similarities between the mechanical behaviour of the Eye Dashwa Lake's rock and those from the Lac du Bonnet batholith near Pinawa, Manitoba.

In terms of Engineering classification, based on the Deere and Miller (1966) classification of intact rock, the Eye Dashwa Lake's formation falls between strong and very strong rock with medium modulus ratio.

*Research Officer, Rock Mechanics Laboratory, Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa, Canada.

**Research Engineer, Atomic Energy of Canada, WNRE, Pinawa, Manitoba. Seconded to Mining Research Laboratories, CANMET, Energy, Mines and Resources, Canada, Ottawa.

DÉTERMINATION DES PROPRIÉTÉS MÉCANIQUES D'ÉCHANTILLONS
DE ROCHE D'ATIKOKAN EN ONTARIO.

par

A. Annor* et R. Jackson**

RÉSUMÉ

On a effectué des mesures afin de déterminer les propriétés mécaniques d'échantillons de roche plutonique de Eye Dashwa Lake, dans le cadre d'un programme de recherche détaillé d'études géomécaniques dirigé par l'Énergie atomique du Canada ltée, dans le but de trouver un moyen d'enfouir les déchets nucléaires dans de la roche plutonique profonde.

Les cinquante-quatre échantillons sont principalement de composition granitique et proviennent du pluton de Eye Dashwa Lake près d'Atikokan (Ontario). Les échantillons ont été étudiés afin d'établir la résistance à la compression uniaxiale, le module de Young, le rapport de Poisson et les indices de vitesse des ondes de compression.

Les résultats des essais ont montré une variation uniforme des propriétés de déformation (E et ν) avec la profondeur. La résistance à la compression uniaxiale et les indices de vitesse des ondes de compression à la pression zéro sont demeurés relativement uniformes avec la profondeur. Ces propriétés ont eu toutefois des renversements de contrainte à certaines élévations; ces renversements sont attribuables aux effets de stabilisation sur les échantillons de laboratoire après le sondage.

Les résultats d'essais sont comparables aux données dans la littérature publiée sur les roches granitiques de composition semblable. Il y avait de plus, des ressemblances entre le comportement mécanique des roches de Eye Dashwa Lake et celui des roches du batholithe du Lac du Bonnet près de Pinawa, au Manitoba.

*Agent de la recherche, Laboratoire de la mécanique des roches, Laboratoires de recherche minière, CANMET, Énergie, Mines et Ressources Canada, Ottawa, Canada.

**Ingénieur de la recherche, Énergie atomique du Canada, WNRE, Pinawa, Manitoba. Affecté provisoirement aux Laboratoires de recherche minière, CANMET, Énergie, Mines et Ressources Canada, Ottawa.

Enfin, selon la classification technique, basée sur la classification de la roche intacte de Deere et Miller (1966), la formation de Eye Dashwa Lake se classe entre la roche résistante et très résistante avec un rapport de module moyen.

FIGURES

<u>No.</u>	<u>Page</u>
1. Standard sample	18
2. Generalized lithology, fracture infillings and occurrence of natural fractures and faults encountered in borehole ATK-1	19
3. Generalized lithology, rock colour and occurrence of veins, zones and natural fractures and their infillings in borehole ATK-5	20
4. Uniaxial elastic properties and dilatational wave velocity profiles for borehole ATK-1 samples	21
5. Uniaxial elastic properties and dilatational wave velocity profiles for borehole ATK-5 samples	22
6. Engineering classification for intact rock for borehole ATK-1 and ATK-5 samples	23
7. Histogram of density for ATK-1 and ATK-5 samples	24
8. Histogram of uniaxial compressive strength for ATK-1 and ATK-5 samples	25
9. Histogram of Young's Modulus for ATK-1 and ATK-5 samples	26
10. Histogram of Poisson's ratio for ATK-1 and ATK-5 samples	27
11. Histogram zero pressure compressive wave velocity for ATK-1 and ATK-5 samples	28
12. Uniaxial elastic properties and dilatational wave velocity profiles for borehole WN-1, WN-2 and WN-4 standard samples	29

CONTENTS

	<u>Page</u>
ABSTRACT	1
RESUME	11
INTRODUCTION	1
GEOLOGICAL DESCRIPTION OF CORE SAMPLES	2
Dilatational Wave Velocity Measurements: ATK-5 and ATK-1* Samples	3
Uniaxial Compressive Strength Measurements	4
ATK-1* and ATK-5 Samples	4
ATK-1 Samples	5
Data Treatment	5
DATA ANALYSIS AND RESULTS	5
Data Summary	6
DISCUSSIONS	6
DATA COMPARISON	7
SCALING FACTORS	8
CONCLUSIONS	8
ACKNOWLEDGEMENTS	9
REFERENCES	10

TABLES

No.

1. Summary of uniaxial mechanical properties and dilatational wave velocity data for borehole ATK-1 samples	13
2. Summary of uniaxial mechanical properties and dilatational wave velocity data for borehole ATK-5 samples	15
3. Statistical summary of mechanical properties data for Eye Dashwa Lakes granite samples (boreholes ATK-1 and ATK-5)	16
4. Summary of literature-referenced uniaxial mechanical properties data for granitic rocks	17

INTRODUCTION

This report constitutes the third in a series of publications being prepared on the mechanical properties of rock formations associated with the Canadian Nuclear Fuel Waste Management Program (NFWMP). The previous two reports of the series (Annor and Wong, 1984; Annor, 1984) describe respectively, the uniaxial strength, and deformation properties of the Chalk River and Lac du Bonnet (WNRE site) formations.

Over the past few years, CANMET and Ontario Hydro have undertaken a joint project to study the properties of rock bodies designated as research areas under the (NFWMP). The investigations have constituted a part of a comprehensive research effort by the Atomic Energy of Canada Limited (AECL) and other government agencies and departments including Energy, Mines and Resources Canada (EMR), to find a safe means of disposing of nuclear waste in deep geologic formations.

Four research areas, located in Chalk River, Ontario, the Lac du Bonnet batholith (at URL and Whiteshell), Manitoba, and in the Eye Dashwa Lakes pluton near Atikokan, Ontario, have been studied to date. The basic mechanical properties characterization component of the investigations, which form the basis of this report, have involved the following tests:

- a) uniaxial compression
- b) dilatational wave velocity, and
- c) Brazilian tensile strength measurements.

The measurements were undertaken to provide data and interpretation for design task activities, to fulfill geosphere modelling objectives, as well as to meet the data requirements of other activities and tasks within the NFWMP.

The objectives of this report are as follows:

- (i) to provide a summary of the mechanical rock properties data for the Eye Dashwa Lakes formation which has been accumulated to date within the EMR's rock property activity (Jackson 1982; Jackson and Mears, 1982 and McKay, 1980).
- (ii) to fulfill geosphere modelling task requirements by accounting, in some detail, how the test data was obtained. Additionally, comparisons are made between the Eye Dashwa Lakes granite data, and values in the published literature for granitic rocks of similar mineralogical compositions (Baumgartner, 1982 and Annor, 1984).

GEOLOGICAL DESCRIPTION OF CORE SAMPLES

The test samples consisted of R-series standard samples from boreholes ATK-1 and ATK-5 in the Eye Dashwa Lakes pluton near Atikokan, Ontario.

The selection of standard samples within the Energy, Mines and Resources, Canada's Rock Property Activity is governed by set criteria, (Larocque 1978), and the samples are distributed as shown in Fig. 1. The standard samples are generally selected to reflect the lithological composition of a borehole, and, as such, are considered to be representative of a formation.

The ATK-1 samples originated between 13.4 and 1140.2 m depths in borehole ATK-1. Similarly the ATK-5 samples were taken between 106.5 and 1228.4 m levels in borehole ATK-5.

Detailed geological core-log and petrographic descriptions of the samples used for the measurements are provided in reports by Katsube et al., (1981) and Chernis et al., (1981).

The rock samples were mainly granitic in composition, grey to pink in colour, medium to coarse-grained, and commonly porphyritic. Phenocrysts of K-feldspar, plagioclase and hornblende were abundant. The major mafic minerals were biotite, hornblende and epidote. These constituted about 10% of the mineral composition of the rock.

An average mineral composition of the Atikokan rock, based on thin section investigations by Chernis (1981), were as follows: about 25.4% quartz, 22.4% K-feldspar, 43.1% plagioclase, 1% hornblende, 4.2% biotite, 1.2% epidote and 2.7% of other minerals.

Detailed investigation of core samples from boreholes in the Eye Dashwa Lakes pluton by Kamineni et al., (1981), indicated the prevalence of alteration zones throughout most of the boreholes. These could be directly associated with the presence of fractures or faults.

Epidote and clinozoisite were the most abundant filling minerals, in association with variable amounts of: hematite, chlorite, quartz, muscovite and fluorite.

DESCRIPTION OF MEASUREMENTS

Sample preparation and testing were carried out to conform as closely as possible with the American Society for Testing and Materials (ASTM) standards (ASTM 1971 1979), and CANMET's Pit Slope Manual Specifications (Gyenge and Herget 1977). Sample preparation, equipment, and testing procedures are also described in the following reports: Annor 1984; Annor and Wong 1984.

SAMPLE PREPARATION

Cylindrical test samples with an average length to diameter ratio of about 2.2 were used for the uniaxial compression and dilatational wave velocity measurements described in this report.

Test samples were cut slightly larger than their final dimensions, using a diamond-saw and water as a coolant. Sample ends were then ground to within 0.03 mm, of being parallel to each other and at right angles to the longitudinal axis. Hardened steel jigs and a lapping wheel were used for this purpose.

The samples were tested in a dry state after surface air drying in the laboratory.

To carry out elastic deformation measurements, strain gauges, oriented to measure axial and circumferential strains, were centered equidistant from the two ends of the specimen. Gauges of similar orientations were located on the opposite sides of the sample. The axial and circumferential gauges were connected in series, to form single active-gauges. These were used in a half-bridge configuration for strain measurements. The gauges used were of the BLH Electronics Co. SR-4, FAE Series.

EQUIPMENT AND TESTING PROCEDURE

Dilatational Wave Velocity Measurements: ATK-5 and ATK-1* Samples

Axial dilatational wave velocity measurements were carried out on test samples already gauged for elastic deformation measurement.

The testing equipment consisted of: transmitting and receiving specimen platens containing piezoelectric transducers, a high voltage pulse generator, a signal amplifier, and a Tektronix Type 555 dual-beam oscilloscope with a delay sweep and a time base resolution of 0.1 micro-second per centi-

meter. The velocity equipment was used with a 1.33 MN hydraulic press (Tinius Olsen Universal Testing Machine) to measure specimen dilatational wave transit time as a function of applied axial load.

The samples and transducer assembly were placed between the platens of the hydraulic press and were axially stressed in increments of about 2.7 MPa to a maximum stress level. Due to structural limitations of the transducer platens, the maximum applied stress was 29 MPa for ATK-1 samples, (McKay 1980), and 43 MPa for ATK-1* and ATK-5 samples (Jackson, 1981; Jackson and Mears 1981). At each incremental stress level, the transmitter piezoelectric transducer excited by the pulse generator was used to send compressive waves into the specimen. These were detected by the receiver piezoelectric transducer. The sweep of the oscilloscope was used with the time delay circuit to display the direct pulse and first arrivals of the transmitted pulse, and to measure specimen time delay.

Prior to individual specimen time delay measurements, the transmitting and receiving transducers were placed in direct contact with each other. The zero delay time of the sonic system was then determined (Annor and Geller, 1979; Gyenge and Herget, 1977). Specimen acoustic velocity (V_p) at each stress level was determined from the relationship

$$V_p = L/(t_p - t_o) \quad (1)$$

where L = specimen length (m)

t_p = time transit (s)

t_o = zero delay time of the sonic system(s)

Uniaxial Compressive Strength Measurements

ATK-1* and ATK-5 Samples

Equipment used to measure axial and circumferential specimen deformation under applied axial load, consisted of two Bruel and Kjaer Type 1526 strain indicators, and a Hewlett Packard 7046 B X-7 recorder.

The bridges were used in a half-bridge configuration. Axial and circumferential strain gauges were used to provide voltage analog outputs of the axial and circumferential strains produced in the sample by axial loading. These analogs were then used to drive the two Y-axis plotters of the Hewlett Packard recorder independently. Axial and circumferential stress-strain curves were obtained in this manner for each of the specimens tested. The

curves were used to determine Young's modulus and Poisson's ratio. The axial load was increased until failure occurred and the failure load noted. Recorder outputs of the axial stress versus strain curves are provided in Jackson (1982), and Jackson and Mears (1982).

ATK-1 Samples

A method similar to that described above was used for carrying out the uniaxial compression measurements of the ATK-1 samples. Each specimen, however, was subjected to three loading and unloading cycles to compensate for the effects of stress relaxation due to drilling. Reported Young's modulus and Poisson's ratio, were determined from the average value of the final two loading and unloading cycles (McKay, 1980). Recorder output of the stress versus strain curves are reported in McKay (1980).

Data Treatment

Young's modulus was calculated for each sample by determining the value of the tangent to the axial strain curve at 50% of failure load. The ratio of the tangent to the transverse strain curve to the tangent to the axial strain curve at 50% failure load, was used to determine the sample's Poisson's ratio. The ultimate compressive strength of each sample was calculated by dividing the sample failure load by sample cross sectional area.

Data Summary

The test results, in terms of boreholes, are summarized in Tables 1 and 2. Table 3 provides a statistical summary of the estimated parameters.

Figures 2 and 3 show the generalized lithology, fracture infillings, and occurrences of natural fractures and faults encountered in boreholes ATK-1 and ATK-5, respectively.

Depth profiles of uniaxial compressive strength, zero pressure compressive wave velocity, tangent modulus of elasticity, and Poisson's ratio for boreholes ATK-1 and ATK-5 are shown in Fig. 4 and 5, respectively.

Figure 6 shows a relationship between Young's modulus and uniaxial compressive strength for the Atikokan samples based on the Deere and Miller Classification for Intact Rock (1966). Modulus ratio for this classification is defined as follows:

$$\text{Modulus ratio} = \frac{\text{tangential Young's modulus at 50\% ultimate strength}}{\text{uniaxial compressive strength}}$$

and is interpreted as follows:

high modulus ratio	>500
medium modulus ratio	200 < modulus ratio < 500
low modulus ratio	<200

Statistical distributions of calculated properties, in terms of sample population, and presented as histograms are also provided in Fig. 7 to 11.

DISCUSSIONS

The test results indicated uniform variation of Young's modulus and Poisson's ratio with depth. Similarly, uniaxial compressive strength and zero pressure compressive wave velocity remained relatively uniform with depth. There is also some indication, however, of trend reversals in these properties between the 500 and 650 m depths in borehole ATK-1, Fig. 4.

The changes in uniaxial compressive strength and zero pressure compressive wave velocity values may be traced to the combined actions of rock alteration and a high concentration of natural fractures present within the 500 and 650 m depths in borehole ATK-1. The core samples from the 500 and 650 m depths (ATK-1) were greyish in colour. Katsube and Kamineni (1982) have correlated the degree of rock sample alterations to colouration. Based on this correlation, altered samples are generally pink in colour. The intensity of the colouration, however, varies with the degree of alteration. This can range from deep pink in the highly altered regions, to different shades of grey in the unaltered areas.

On the basis of Katsube and Kamineni's (1982) suggested colour criteria for rock alteration, it would appear that the uniaxial compressive strength and zero pressure compressive wave velocity values for the altered pink granite samples are higher than for the unaltered grey coloured samples (Tables 1 and 2). In this regard, there seem to be similarities in mechanical properties for the Lac du Bonnet and the Eye Dashwa Lakes granitic formations. There is, however, a marked contrast between the deformational properties

(Young's modulus and Poisson's ratio) of the two formations (Fig. 4, 5 and 12). No definable trends are noticed with depth for the Atikokan samples as compared to the Lac du Bonnet rock. The difference is due to the fact that, in the Lac du Bonnet formation, altered and unaltered rock are limited to distinctive zones. Altered zones within the Eye Dashwa Lakes pluton, however, are not as clearly defined, and seem to be distributed at random intervals throughout the lithology.

The uniaxial properties of rock samples from both the Eye Dashwa Lakes pluton and the Lac du Bonnet batholith can be said to be influenced largely by chemical alteration. The unaltered rock samples are weaker in compression because these are influenced significantly by the effects of stress relief. On the other hand, the altered pink rock samples are stronger in compression as a result of alteration, which reduces the ability of the samples to undergo stress relaxation upon drilling.

When comparing the data from different boreholes, the mean and standard deviation for uniaxial compressive strength of test samples originating from borehole ATK-5 were 221 and 27 MPa, respectively. These should be compared with 208 and 24 MPa, for the ATK-1 samples. The mean compressive strength, between samples from the two boreholes differ only by 6%. This can be attributed to experimental error. On the other hand, mean and standard deviation Young's modulus values were 69.0 and 15.2 GPa, respectively, for ATK-5 samples. These should be compared with 75.9 and 14.9 GPa, for the ATK-1 rock. The difference between the mean Young's modulus of the ATK-1 and ATK-5 samples is about 10%. This compares well with an observed difference of about 12% between the mean Poisson's ratios of samples from the two boreholes (0.28 ± 0.06 for ATK-5 as compared to 0.25 ± 0.04 for ATK-1). The slight differences in properties within the two boreholes, could be due to differences in the degree of sample alteration, as well as to fracture densities. The ATK-5 samples were predominantly grey-coloured, implying less alteration as compared with the pink altered ATK-1 samples.

DATA COMPARISON

In comparison with literature-referenced data, the test results compare favourably with published data for granitic rocks with similar mineral compositions as the Eye Dashwa Lakes formation. Considering the wide range

of published data on granitic rocks, the test results were compared only with published data for granitic rocks, with densities in the range of 2.61 to 2.68 Mg/m³. A summary of the published reference data is provided in Table 4.

In terms of engineering classification for intact rock by Deere and Miller, (1966), the Eye Dashwa Lakes granitic formation falls into the range of high strength to very high strength rock, with a medium modulus ratio. It is similar to the Lac du Bonnet formation in terms of this classification.

SCALING FACTORS

With regards to scaling factors to be applied between the in-situ rockmass strength and laboratory-determined small scale properties, Hoek and Brown (1980) have suggested the following approximate empirical relationship between uniaxial compressive strength (Q_u), and test sample diameter (d), for unjointed intact rock:

$$Q_u = Q_{u50} (50/d)^{0.18} \quad (5)$$

(for test sample diameters between 10 and 200 mm)

where Q_{u50} is uniaxial compressive strength of a specimen of 50 mm diameter.

With respect to deformational properties, Hauze (1980) has determined the following generalized relationship between field and laboratory measured Young's modulus, based on literature review on large geotechnical projects:

$$0.20 < E_f/E_l < 0.60 \quad (6)$$

where E_f and E_l refer to Young's moduli determined in the field and laboratory, respectively. It is recommended that some field tests on large volumes of rock be carried out to provide verification data (Annor, 1984).

CONCLUSIONS

In general, the experimental results indicated relatively uniform variations of strength, deformational, and acoustic properties with

increasing sample depth. There were, however, trend reversals in strength and acoustic velocity values in borehole ATK-1 due to rock alteration and large in situ fracture densities.

There are, to some extent, similarities in the elastic properties of rock samples from the Eye Dashwa Lakes pluton and those from the Lac du Bonnet batholith (Annor, 1984). The pink altered samples from either pluton displayed higher uniaxial compressive strength and zero pressure compressive wave velocity than the grey samples.

In addition, test samples originating from the vicinity of fracture zones were generally weaker in compression. This was probably due to physical alteration (micro cracking). This behaviour seemed to have occurred independent of a sample's location in a borehole.

The test results compare favourably with published data in the literature on granitic rock with similar mineralogical composition as the Eye Dashwa Lakes granite.

In terms of engineering classification for intact rock by Deere and Miller (1966), the Eye Dashwa Lakes formation falls in the range of high strength to very high strength rock with medium modulus ratio, and similar to the Lac du Bonnet formation on the basis of this classification.

ACKNOWLEDGEMENTS

The authors wish to thank the following people for their contributions to this report: J. Folta and D. Dugmore for preparing the drawings, A.S. Wong for his assistance with the geological description, and Dr. J. Udd for his critical review of the manuscript.

REFERENCES

1. Annor, A. 1984; Mechanical properties of rock samples from Pinawa, Manitoba; CANMET, Mining Research Laboratories; Report ERP/MRL 84-48(TR).
2. Annor, A. and L. Geller, 1978b; Dilatational velocity, Young's modulus, Poisson's ratio; uniaxial compressive strength and Brazilian tensile strength for WNR1 samples; CANMET, Mining Research Laboratories; Technical Data 303410-M03/78.
3. Annor, A. and R. Jackson, 1982; Summary of uniaxial elastic properties and thermal expansion data for Pinawa granite samples (URL-1,2,5 and WN-1, 2 and 4); CANMET, Mining Research Laboratories; Report MRP/MRL 82-82(OP).
4. Annor, A. and A.S. Wong, 1984; Mechanical properties of rock samples from Chalk River, Ontario; CANMET, Mining Research Laboratories; Report ERP/MRL 84-33(TR).
5. ASTM, 1971a; Standard test for unconfined compressive strength of intact rock specimens; ASTM test D2937-71A.
6. ASTM, 1971b; Standard test for splitting tensile strength of cylindrical concrete specimens; ASTM test C496-71.
7. Baumgartner, P. 1983; Summary of rock properties testing (Phase II) and data base generation; AECL Whiteshell Nuclear Research Establishment Memorandum No. AGHB83-120.
8. Chernis, P.J. 1981; Petrographic description of ATK-1 Standard P samples. Technical Data T.M. 303405-M01/81, Electrical and Seismic Rock Property Laboratory, Geological Survey of Canada, Ontario.

10. Deere, J.J. and R.P. Miller, 1966; Engineering classification and index properties for intact rock; Air Force Weapons Laboratory, Technical Report No. AFWL-TR-65-116.
11. Dugal, J.J.B. 1984; Unpublished notes on Sperry-Sun directional survey reports for drillholes ATK-1 and ATK-5; Terrain Sciences Division, Geological Surveys of Canada, Ottawa.
12. Gyenge, M. and G. Herget, 1977; Pit slope manual supplement 3-2, Laboratory tests for design parameters; CANMET Report 77-26; 74 p.
13. Hauze, F.E. 1980; Scale effects in the determination of rockmass strength.
14. Hoek, E. and E.T. Brown, 1980; Underground excavation in rock; The Institution of Mining and Metallurgy, London; pp 131-159.
15. Jackson, R. 1982; "Dilatational velocity, Young's modulus, Poisson's ratio and uniaxial compressive strength for ATK-5 samples"; CANMET Division Report ERP/MRL 82-114(TR).
16. Jackson, R. and A. Mears, 1982; "Dilatational velocity, Young's modulus, Poisson's ratio and uniaxial compressive strength for ATK-1 samples"; CANMET Division Report ERP/MRL 82-6(TR).
18. Katsube, T.J., P.J. Chernis, and C.F. Hyslop, 1980; Preliminary investigation of ATK-1 standard samples; Technical Data TM 303405-M18/80 Electrical and Seismic Rock Property Laboratory, Geological Survey of Canada, Ottawa.
19. Kamineni, D.C. and J.J.B. Dugal, 1981; A preliminary report and interpretation of alteration in the Eye Dashwa Lakes pluton. Atomic Energy of Canada Limited Technical Record, TR-178. Whiteshell Nuclear Research Establishment, Pinawa, Manitoba.

20. Kaminen, D.C. and T.J. Katsube, 1981; Geological factors controlling the matrix permeability in crystalline rocks; Technical Report TM-303405-M09/81 Electrical and Seismic Rock Property Laboratory, Geological Survey of Canada, Ottawa.
21. Larocque, G.E. 1978; Memorandum on standard sample selection. Rock Mechanics Laboratory, CANMET.
22. Lama, R.D. and V.S. Vutukuri, (1978); Handbook on mechanical properties of rock; Vol. II; Appendix II; pp 315-465; Trans. Tech. Publications.
23. McKay, D.A. 1980; AECL core testing program, CR-5, CR-8 CR-9, WN-4, ATK-1 series cores; Ontario Hydro Research Division Report 80-431-K.

Table 1 - Summary of uniaxial mechanical properties and dilatational wave velocity data for borehole ATK-1 samples

Specimen I.D.	Borehole characteristics		Specimen characteristics							Dilatation velocity				Rock type and special features
	Approximate vertical depth (m)	Approximate elevation (m)	Length (mm)	Diameter (mm)	Density (Mg/m ³)	Compressive strength (MPa)	Elastic modulus (GPa)	Poisson's ratio	Vp (at 0.1 MPa) (km/s)	Velocity under axial compression		Vp ($\sigma_v = 29$ MPa) (km/s)		
ATK 1- 13.40	12.8	433.5	N/A	N/A	2.65	219	123.4	0.39	5.70	5.88		5.70	5.88	Granite-pink
ATK 1- 40.10	38.5	407.8	N/A	N/A	2.65	221	82.4	0.24	5.25	5.66		5.25	5.66	Granite-pink- ish-grey
ATK 1- 79.50	76.2	370.1	N/A	N/A	2.64	228	87.9	0.28	5.36	5.79		5.36	5.79	Granite-pink
ATK 1- 94.60	90.3	356.0	N/A	N/A	2.63	185	82.4	0.24	5.30	5.68		5.30	5.68	Granite-pink (contains par- tially filled fractures)
ATK 1-110.90	107.0	339.3	N/A	N/A	2.64	240	119.2	0.37	5.68	5.96		5.68	5.96	Granite-pink
ATK 1-128.60	123.3	323.0	N/A	N/A	2.65	199	82.5	0.23	5.27	5.88		5.27	5.88	Granite-pink
ATK 1-163.30	156.5	289.8	N/A	N/A	2.65	229	79.0	0.25	4.75	5.49		4.75	5.49	Granite-pink- ish-grey
ATK 1-174.20	167.0	279.3	N/A	N/A	2.65	230	81.3	0.24	5.39	5.78		5.39	5.78	Granite-pink
ATK 1-238.10	227.5	218.8	N/A	N/A	2.65	223	79.3	0.25	4.99	5.53		4.99	5.53	Granite-pink- ish-grey
ATK 1-283.60	270.3	176.0	N/A	N/A	2.66	201	81.8	0.25	5.34	5.75		5.34	5.75	Granite-pink
ATK 1-320.25	305.0	141.3	95.86	44.73	2.66	226	67.4	0.25	4.25	5.79		4.25	5.79	Granodiorite
ATK 1-361.40	342.8	103.5	95.99	44.81	2.65	231	72.3	0.21	5.15	6.06		5.15	6.06	Granodiorite
ATK 1-400.70	379.0	67.3	95.71	44.45	2.68	227	72.4	0.20	5.13	5.98		5.13	5.98	Granodiorite
ATK 1-433.50	409.1	37.2	96.42	44.81	2.65	226	69.7	0.25	4.87	5.92		4.87	5.92	Granodiorite
ATK 1-475.50	447.5	-1.2	95.76	44.70	2.65	221	52.8	0.20	4.85	5.95		4.85	5.95	Granodiorite
ATK 1-505.40	474.6	-28.3	N/A	N/A	2.65	212	75.2	0.24	3.66	4.64		3.66	4.64	Granite-grey
ATK 1-540.10	506.1	-59.8	N/A	N/A	2.65	179	67.0	0.24	3.63	4.57		3.63	4.57	Granite-grey
ATK 1-594.20	554.9	-108.6	N/A	N/A	2.64	162	64.8	0.28	3.11	4.39		3.11	4.39	Granite-grey
ATK 1-630.40	587.4	-141.1	95.78	45.09	2.65	170	56.9	0.20	3.76	5.31		3.76	5.31	Quartz monzo- nite
ATK 1-641.20	623.8	-177.5	94.74	44.96	2.65	194	60.3	0.28	4.51	5.66		4.51	5.66	Granodiorite
ATK 1-715.20	662.8	-216.5	95.78	44.63	2.66	202	75.7	0.26	5.68	6.10		5.68	6.10	Granodiorite
ATK 1-747.30	691.0	-244.7	97.03	44.96	2.65	216	62.6	0.24	4.65	5.56		4.65	5.56	Granodiorite
ATK 1-788.30	726.7	-280.4	95.45	44.53	2.66	193	58.3	0.26	4.20	5.36		4.20	5.36	Granodiorite

Table 1 - Cont'd

Borehole characteristics				Specimen characteristics				Dilatation velocity			
Approximate				Approximate				Velocity under			
Specimen	vertical depth (m)	elevation (m)	Length (mm)	Diameter (mm)	Density (Mg/m ³)	Compressive strength (MPa)	Elastic modulus (GPa)	Poisson's ratio	Vp (at 0.1 MPa) (km/s)	Vp axial compression (at 29 MPa) (km/s)	Rock type and special features
ATK 1-812.50	747.7	-301.4	N/A	N/A	2.65	190	69.2	0.25	3.85	4.88	Granite-pink- ish-grey
ATK 1-848.90	779.5	-333.2	N/A	N/A	2.59	223	72.0	0.22	4.61	5.17	Granite-pink- ish-grey
ATK 1-902.15	824.6	-378.3	N/A	N/A	2.65	220	71.3	0.27	3.87	4.75	Granite-pink- ish-grey
ATK 1- 924.00	843.0	-396.7	N/A	N/A	2.65	209	80.8	0.25	5.04	5.50	Granite-grey- pink
ATK 1- 979.90	889.8	-443.5	N/A	N/A	2.65	189	72.0	0.27	4.14	4.89	Granite-grey
ATK 1-1021.40	924.2	-477.9	N/A	N/A	2.65	191	73.5	0.30	3.45	4.65	Granite-pink- ish-grey
ATK 1-1035.00	935.4	-489.1	N/A	N/A	2.63	250	83.5	0.23	5.31	5.55	Granite-grey- pink
ATK 1-1063.60	958.9	-512.6	N/A	N/A	2.65	180	64.8	0.21	3.28	4.41	Granite-grey
ATK 1-1079.10	972.0	-525.7	N/A	N/A	2.65	207	87.4	0.17	4.57	5.11	Granite-grey- pink (foliated)
ATK 1-1097.70	986.5	-540.2	N/A	N/A	2.64	180	86.0	0.26	5.12	5.43	Granite-grey- ish-pink (con- tained visible cracks)
ATK 1-1120.50	1006.3	-560.0	N/A	N/A	2.64	257	87.6	0.26	5.76	5.95	Granite-grey- ish-pink (epidote filled fractures)
ATK 1-1140.20	1021.6	-575.3	N/A	N/A	2.64	154	55.2	0.23	2.14	3.76	Granite-pink- ish-grey (foliated)
Mean					2.65	208	75.9	0.25	4.62	5.24 (#5.77)	
Std. Dev.					0.011	24	14.9	0.04	0.86	0.60 (#0.28)	
										($\sigma_v = 43$ MPa)	

Table 2 - Summary of uniaxial mechanical properties and dilatational wave velocity data for borehole samples

Specimen	Approximate vertical depth (m)	Specimen characteristics					Dilatation velocity				Rock type and special features
		Approximate elevation (mm)	Length (mm)	Diameter (mm)	Density (Mg/m ³)	Compressive strength (MPa)	Elastic modulus (GPa)	Poisson's ratio	Vp (at 0.1 MPa) (km/s)	Velocity under axial compression Vp (σv = 45 MPa) (km/s)	
ATK 5- 106.50	103.1	349.0	97.56	44.70	2.66	242	96.2	0.33	4.76	5.69	Granite-grey
ATK 5- 224.40	212.2	235.8	94.62	44.45	2.66	229	98.0	0.39	4.87	5.70	Granite-grey- ish-pink
ATK 5- 337.50	323.4	128.6	95.15	44.70	2.66	224	64.1	0.34	4.76	5.65	Granite-grey
ATK 5- 424.00	404.3	47.7	92.71	44.86	2.66	241	71.9	0.30	5.33	5.83	Granite-pink- ish-grey
ATK 5- 534.20	505.6	-53.6	95.81	44.68	2.66	212	61.0	0.27	3.94	5.28	Granite-grey
ATK 5- 625.60	587.4	-135.4	95.73	44.88	2.68	235	62.5	0.19	5.01	5.73	Granite-pink- ish-grey
ATK 5- 708.70	659.1	-207.1	95.61	44.25	2.73	206	57.5	0.27	4.15	5.25	Granite-grey
ATK 5- 818.10	752.1	-300.1	94.72	44.81	2.65	178	55.0	0.20	3.84	5.15	Granite-grey
ATK 5- 867.70	793.9	-341.8	96.14	44.75	2.66	202	61.7	0.28	3.92	5.33	Granite-grey
ATK 5- 918.20	836.2	-384.2	95.73	44.83	2.65	217	59.5	0.25	3.92	5.32	Granite-yel- lowish-grey
ATK 5- 951.30	863.3	-411.2	96.75	44.81	2.66	223	97.1	0.36	4.22	5.50	Granite-pink- ish-grey
ATK 5- 975.60	883.0	-430.9	97.21	44.35	2.66	208	59.9	0.23	3.79	5.21	Granite-yel- lowish-grey
ATK 5-1050.10	941.6	-489.5	96.11	44.55	2.56	217	63.3	0.25	3.72	5.52	Granite-pink- ish-grey
ATK 5-1107.90	984.9	-532.9	96.44	44.83	2.66	185	57.0	0.31	4.04	5.45	Granite-pink- ish-grey
ATK 5-1228.40	1071.0	-619.0	97.18	44.40	2.65	293	70.8	0.22	4.70	5.70	Granite-pink- ish-grey
Mean			95.83	44.66	2.66	221	69.0	0.28	4.33	5.49	
Std. Dev.			1.23	0.21	0.003	27	15.2	0.06	0.52	0.22	

Table 3 - Summary of uniaxial elastic property data

Borehole identification	Principal rock type	No. of samples	Uniaxial			P-wave velocity at zero press.
			Density (Mg/m ³)	compressive strength (MPa)	Young's modulus (GPa)	Poisson's ratio
ATK-1 and ATK-5	Granite and granodio- rite	50	No. of values	50	50	50
			range	2.56 to	154 to	0.17 to
				2.73	293	0.39
			Mean	2.65	212	0.26
			Std. Dev.	0.02	26	0.05
					52.8 to	2.14
					123.4	5.76
					73.9	4.53
					15.2	0.78

Table 4 - Summary of literature-referenced uniaxial mechanical properties data for granitic rocks

Location and granitic rock description		Uniaxial density	Compressive strength	Modulus of elasticity	Poisson's ratio	Tensile strength	Reference
		ρ (Mg/m ³)	Qu (MPa)	E (GPa)	ν	σ_t (MPa)	
1 U.S.A. Md., contains quartz and syenite		2.65	250.97	52.54	-	20.68 (R)	Wuerker, 1956
2 U.S.A. Pikes Peak, dense, mg		2.64	226.0	70.6	0.18	11.9	Miller, 1965
3 U.S.A. Barre, Vt., and syenite		2.64	194.4	61.4	0.39	10.7	Miller, 1965
4 U.S.A. Rose Granite Pedernal Hills, N.M.		2.64	308.0	69.64	0.28	-	Michalopoulos and Triandafilidis, 1976
5 U.S.A. Raymond, Calif. Pedernal Hills, N.M.		2.64	178.0	58.6	0.26	-	Michalopoulos and Triandafilidis, 1976
6 Canada, Grenville Que, Cg, 80% orthoclase		2.61	172.0	65.8	-	-	Coates & Parsons, 1966
7 U.S.A., Barre, Vt. Perpendicular to bedding		2.64	200.0	58.6	-	13.5	Hawkes et al, 1973
8 U.S.A., Mg-Cg	(a)	2.66	228.91	30.4*	0.04*	19.99	Obert et al, 1946
	(b)	2.66	225.15	27.4*	0.10	25.37 (R)	
	(c)	2.66	244.07	44.2*	0.31*	18.41 (R)	
9 Lac du Bonnet granite	mean	2.65	192	68.2	0.26	11.12	Annor and Jackson, 1982
(WNRE)		0.03	29	4.9	0.04	1.12	
		(N-32)	(N-46)	(N-46)	(N-46)	(N-16)	
10 Lac du Bonnet granite	mean	2.59	185	66.8	0.27	8.9	1982
(URL site)	Std. Dev.	0.02	24	9.0	0.05	1.0	

Numbers 1-8 were compiled and condensed from: Lama and Vutukuri, (1978)

* Dynamic test values

R-test in bending

ROCK PROPERTY ACTIVITY; STANDARD SAMPLE
DISTRIBUTION SCHEME (1979/80)

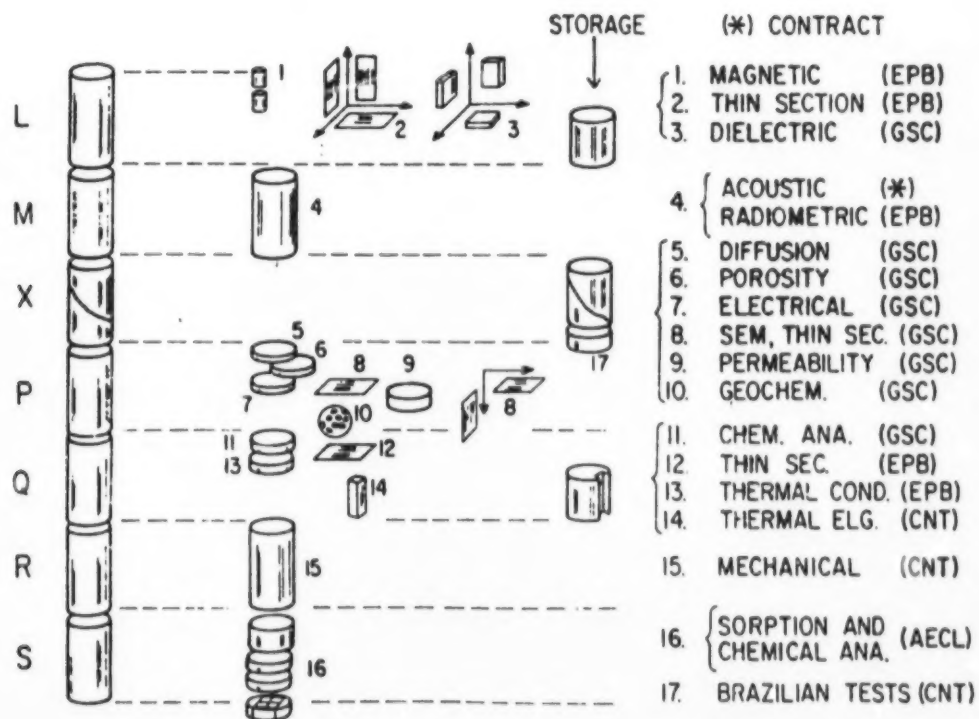


Fig. 1 - Standard sample

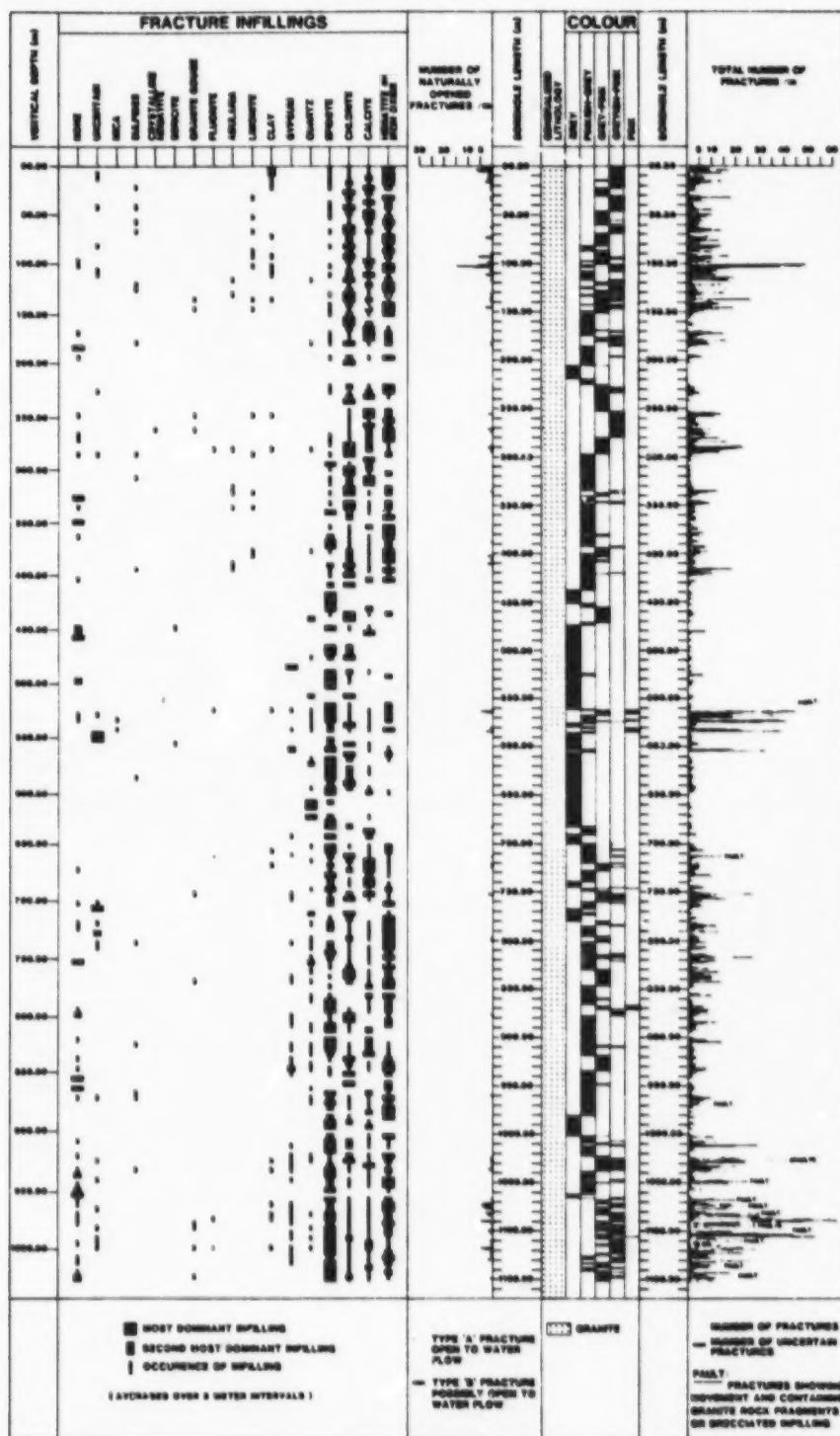


Fig. 2 - Generalized lithology, fracture infillings and occurrence of natural fractures and faults encountered in borehole ATK-1



Fig. 3 - Generalized lithology, rock colour, and occurrence of veins, zones, and natural fractures and their infillings in borehole ATK-5

Borehole ATK-1 Profiles

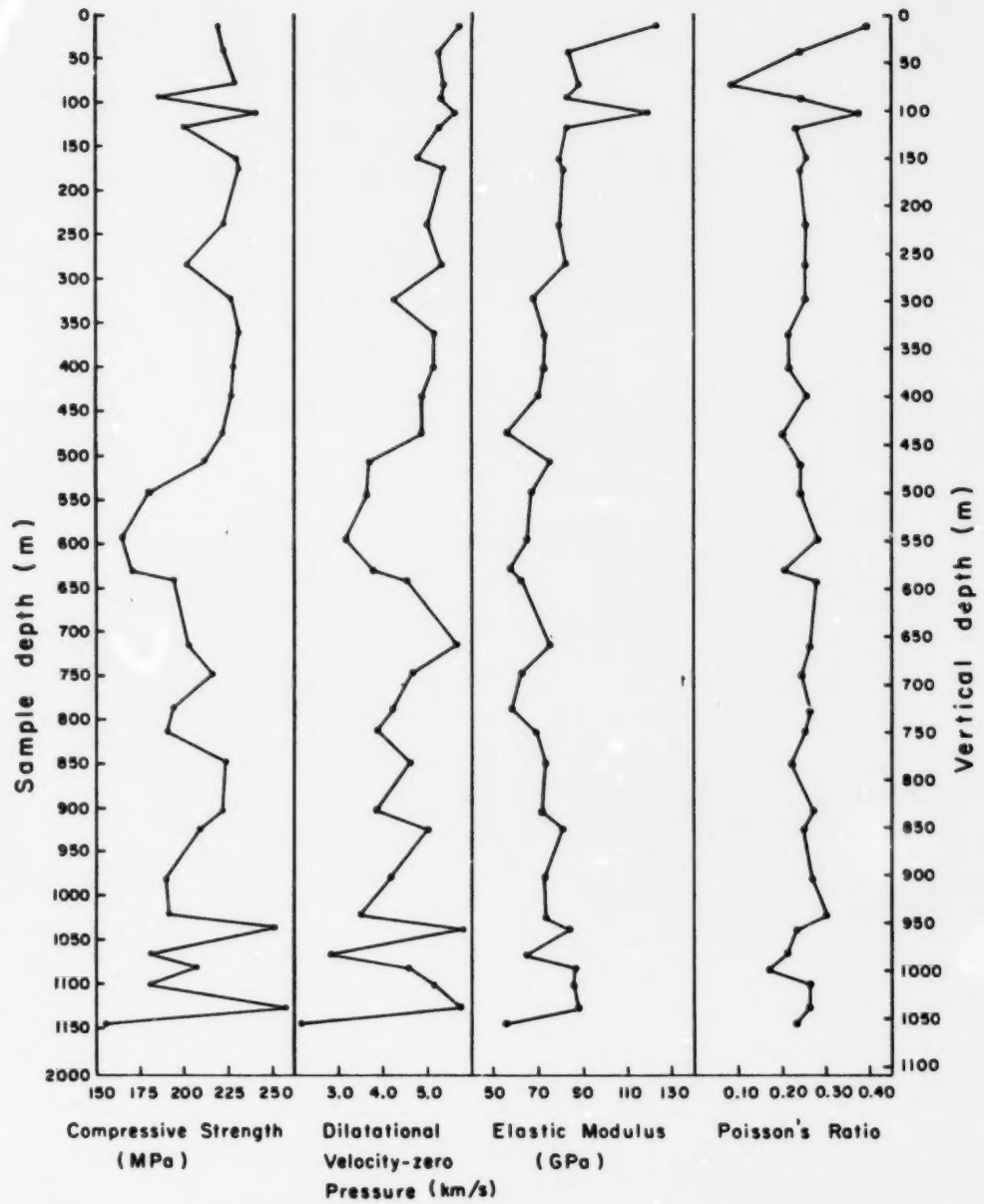


Fig. 4 - Uniaxial elastic properties and dilatational wave velocity profiles for borehole ATK-1

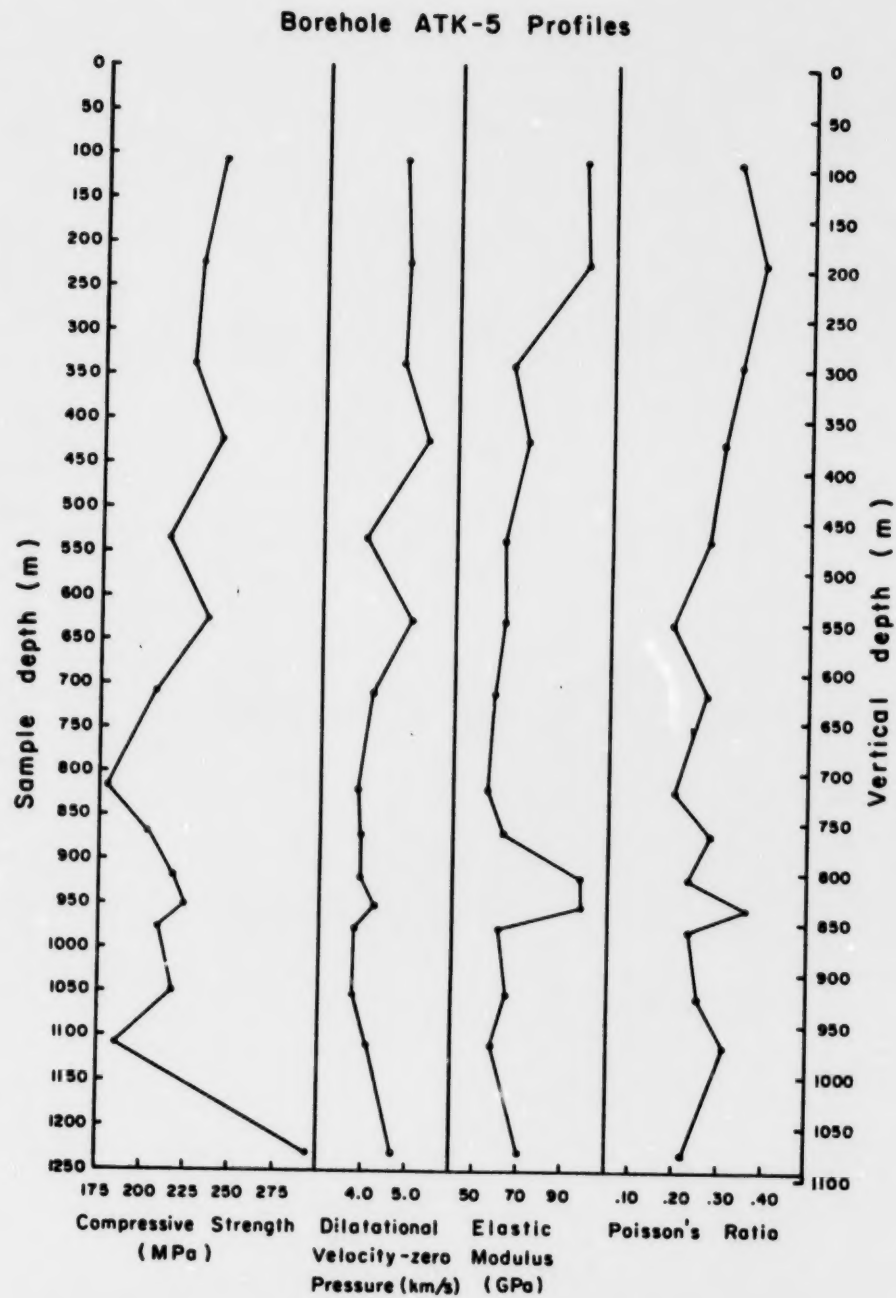
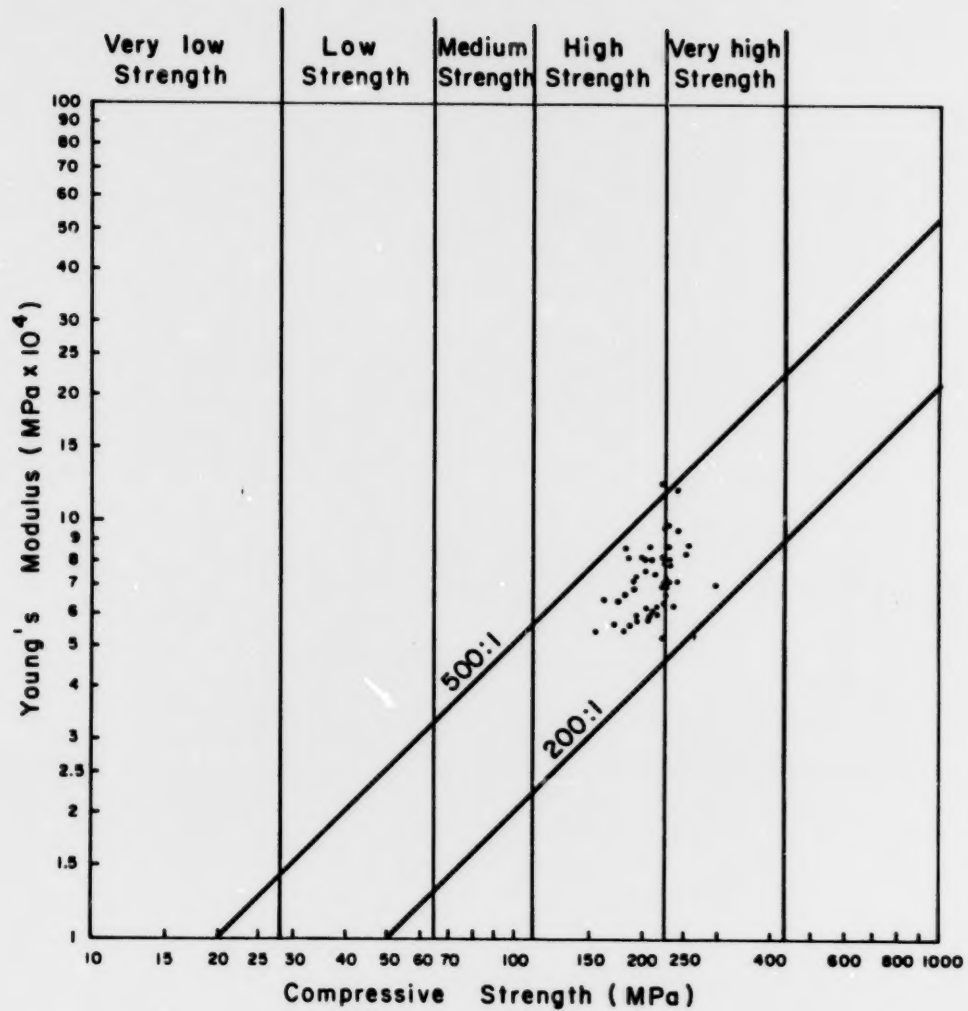


Fig. 5 - Uniaxial elastic properties and dilatational wave velocity profiles for borehole ATK-5



(After Deere and Miller, 1966)

Fig. 6 - Engineering classification of intact rock for borehole ATK-1 and ATK-5 samples

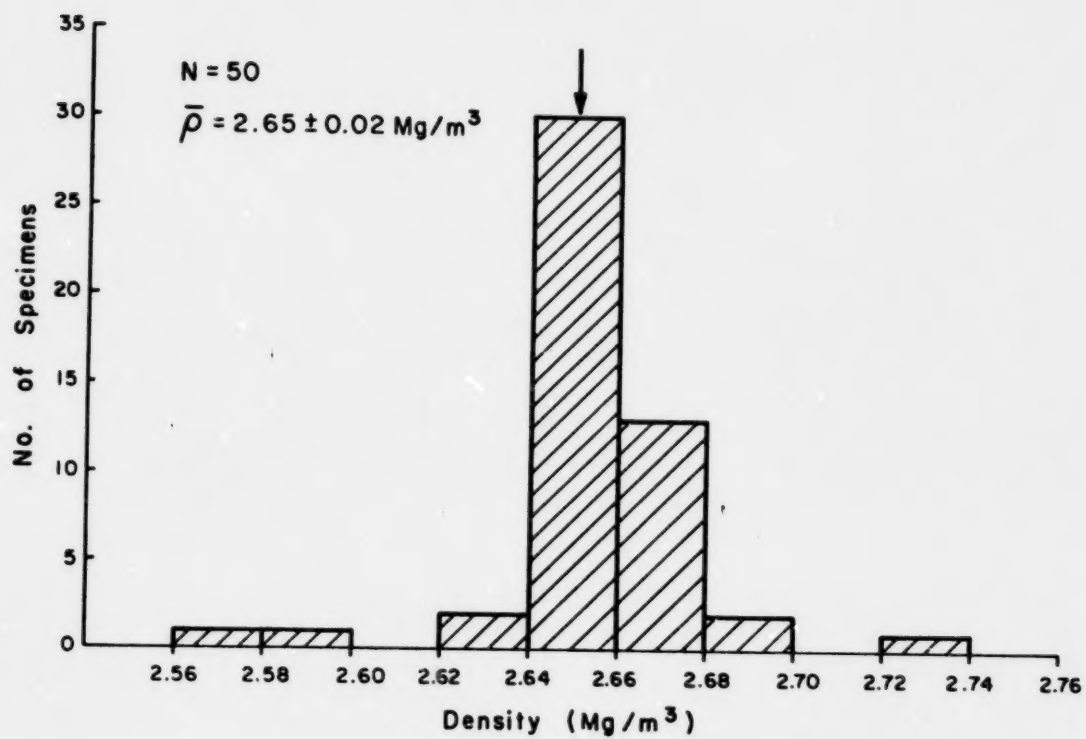


Fig. 7 - Histogram of density for ATK-1 and ATK-5 samples

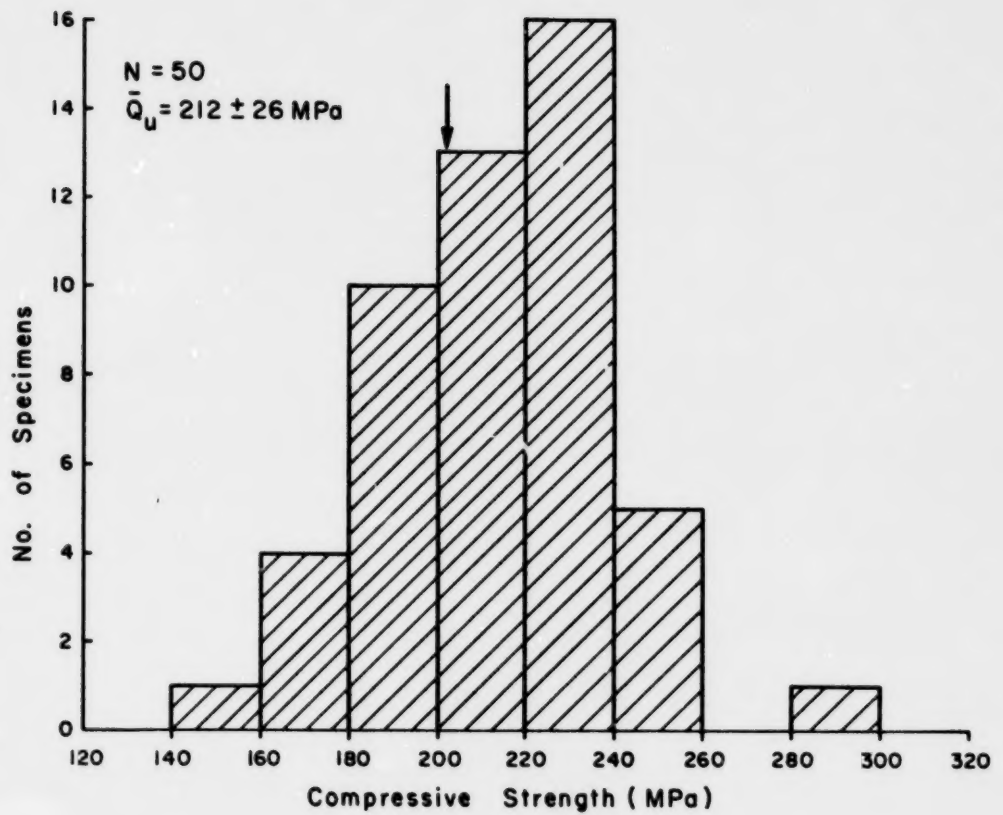


Fig. 8 - Histogram of uniaxial compressive strength for ATK-1 and ATK-5 samples

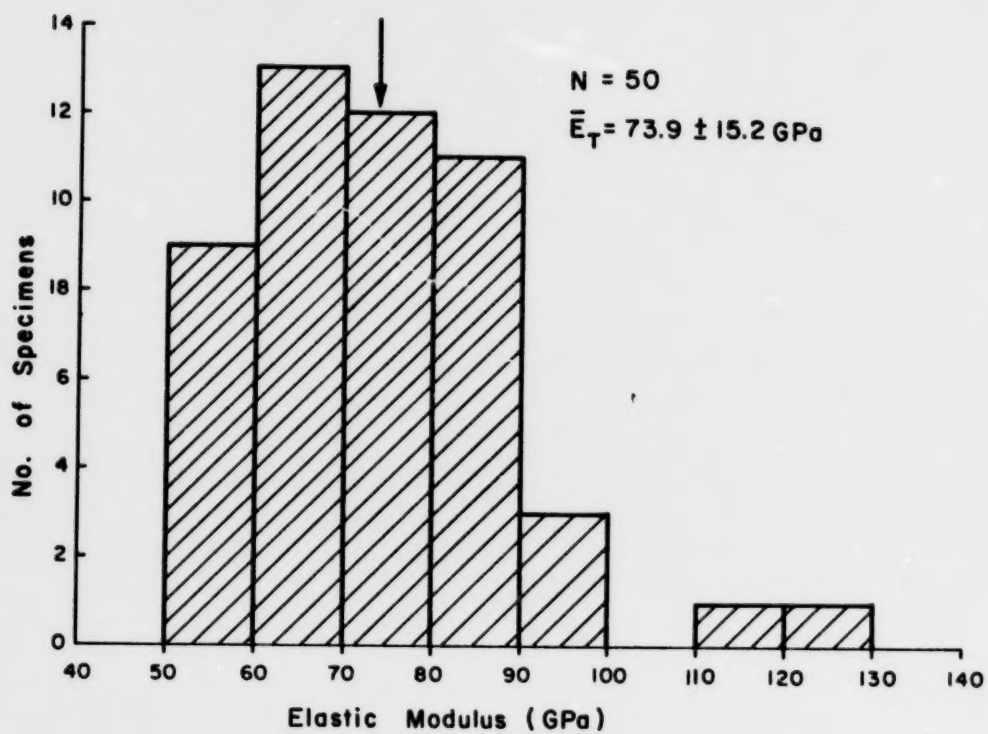


Fig. 9 - Histogram of Young's modulus for ATK-1 and ATK-5 samples

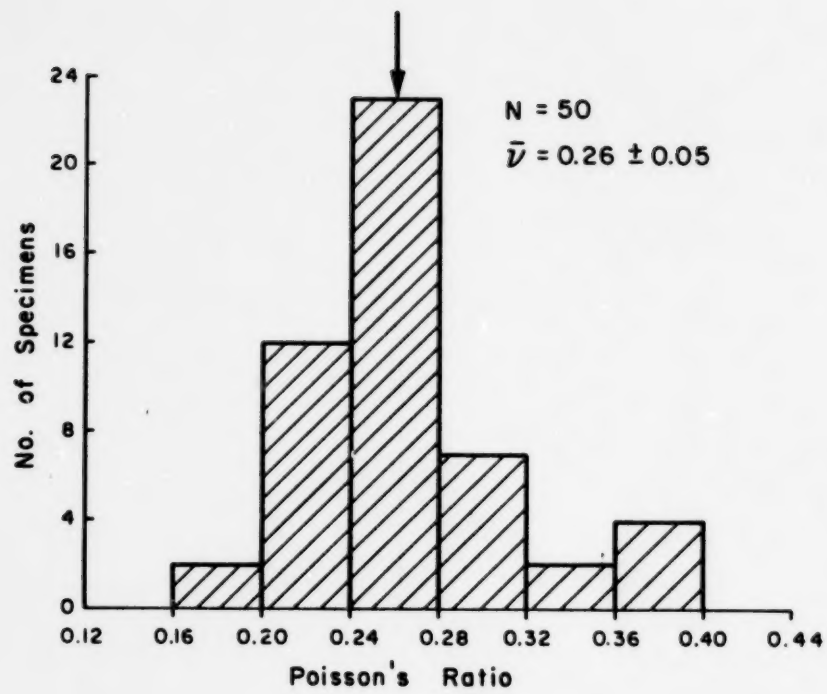


Fig. 10 - Histogram of Poisson's ratio for ATK-1 and ATK-5 samples

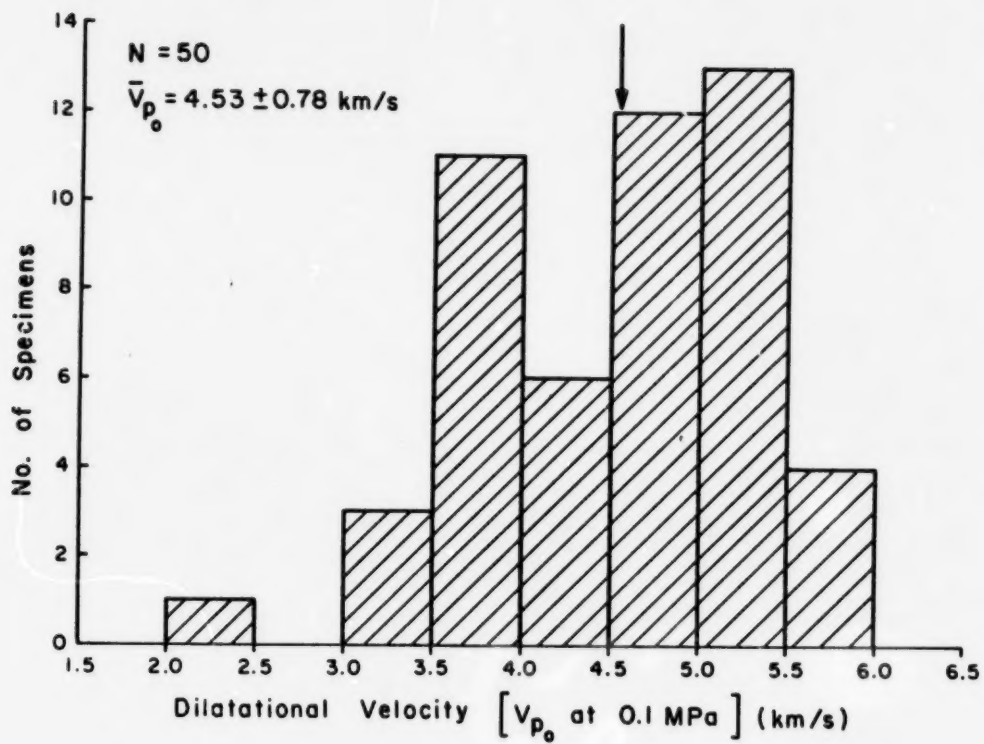


Fig. 11 - Histogram of zero pressure compressive wave velocity for boreholes ATK-1 and ATK-5

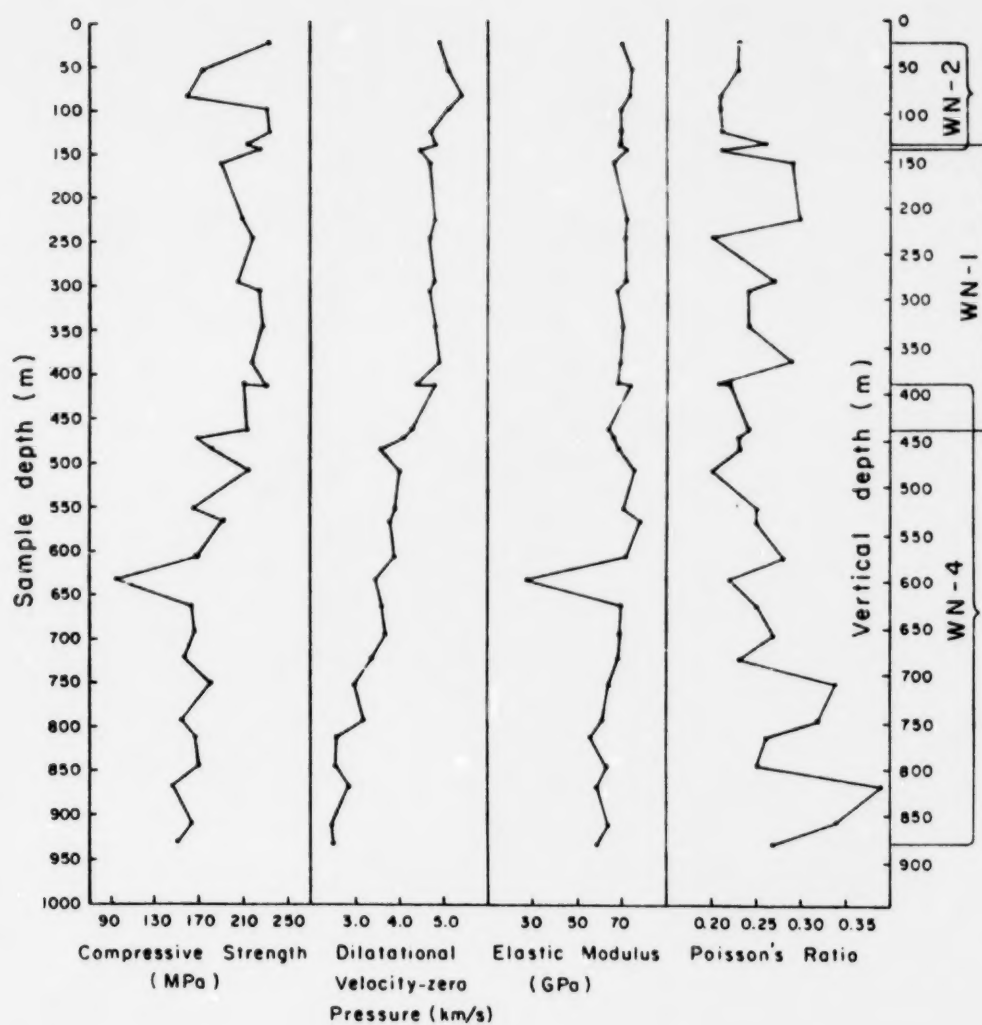


Fig. 12 - Uniaxial elastic properties and dilatational wave velocity profiles for borehole WN-1, WN-2 and WN-4 standard samples